

# 607: Strong Coupling Improved Equilibration In High Energy Nuclear Collisions

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**Abstract.** In high energy nuclear collisions, most calculations on the early equilibration of the parton plasma showed that the system does not come close to full equilibrium, especially for the fermion components. However, since the system is constantly evolving, the cooling effect due to expansion will lead to a decrease of the average parton energies. So the interactions should be enhanced by a corresponding increase of the running coupling. We show that this leads to a faster and improved equilibration. This improvement is more important for the fermions compensating partially for their weaker interactions and slower equilibration. WU-B 97/30

## 1 Introduction

High energy nuclear collisions have become a subject of great interest in the last decade or so, bolstered by the experiments at Brookhaven AGS and CERN SPS and culminating in the constructions of the soon-to-be running larger higher energy colliders like RHIC and LHC. One attempts in these experiments to create and study deconfined matter. An obvious question is how to identify matter in the new phase. This is done by the various proposed particle signatures such as  $J/\psi$  suppression, strangeness enhancement and excess at low mass dileptons. A question of similar importance is the evolution of matter in the new state which influences directly these signatures produced during the deconfined phase and indirectly in modifying the initial conditions of the subsequent hydrodynamic expansion. Final hadron yields are closely related to the generated entropy which is mainly produced in the initial parton creation and subsequent parton interactions. This precisely depends on the time evolution. We study this in order to gain a better understanding of the evolution and the equilibration process.

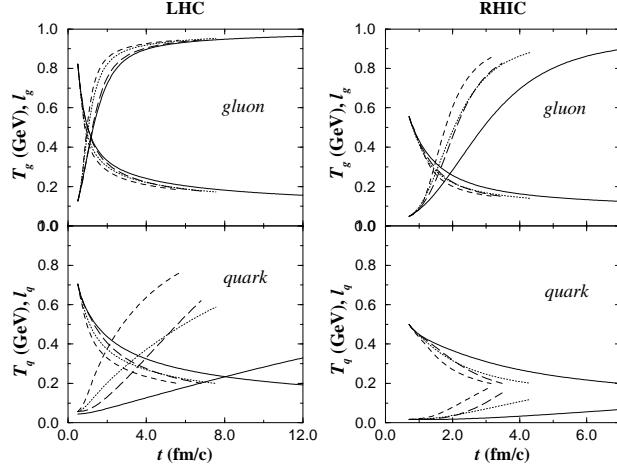
The main questions of equilibration is whether thermalization is fast, if parton chemical equilibration can be completed before the start of the phase transition and the possible duration of the deconfined phase. Whereas approximate thermalization should be achieved in the first few fm/c as shown by models like parton cascade [1, 2], completion of chemical equilibration is impossible for all present existing models [3, 4, 5, 6]. As to the duration of the parton phase, it depends on various factors. Actually the answers to all three questions depend on the inherent uncertainties associated with these studies. They are the initial conditions, infrared cutoff parameter and the value of the coupling used. One can raise the question as to whether some of these

can be exploited to determine better or improve the equilibration process such as parton chemical equilibration. To change the initial conditions to get better answers is too arbitrary and irrelevant since one can vary no more than the energy/nucleon and centrality of the collision in the experiments. Infrared cutoff, which is usual in perturbative QCD is actually not needed in a deconfined medium because of the screening effect of the latter. Finally the third possibility is the coupling. One usually uses a value of  $\alpha_s = 0.3$  for an average momentum transfer of around 2.0 GeV. However, during the time evolution, the parton energies drop considerably due to the longitudinal expansion and particle creation. Therefore so will the average momentum transfer drops in time and the coupling, which is treated as a kind of average value here, cannot stay at a constant value. The exploitation of this effect will be the main subject of this talk.

## 2 Strong Coupling Improvements on Equilibration

Our method for this investigation is based on solving Boltzmann equation with the relaxation time approximation and explicit construction from perturbative QCD for the collision terms. All binary collisions and 2-to-3 gluon multiplication as well as the reverse process are included at the tree level [5, 6]. In accordance with our discussion in the introduction, we study the effect of the coupling on the equilibration. This is done by comparing results with various fixed values for the coupling and a time varying coupling obtained by using the one-loop running  $\alpha_s$  formula and evaluating the coupling at the scale, at any time, of the average parton energy. The reason being that the average momentum transfer in parton scatterings should be of the order of the average parton energy. This latter approach allows the system to determine its interaction strength and removes an otherwise free parameter, whose value was usually chosen with perturbative QCD in mind. This will be an advantage as we will see presently because the results on equilibration do depend on the value of  $\alpha_s$  used [7]. We use the initial conditions from HIJING for our time evolution after allowing for the resulting parton gas to free stream to an isotropic distribution [4].

To examine the state of the equilibration, we plotted in Fig. 1, the quark and gluon fugacities and their temperature estimates as a function of time and in Fig. 2 the pressure ratios, which is a check of kinetic equilibration. The various curves are for  $\alpha_s = 0.3, 0.5, 0.8$  and for the time evolving coupling  $\alpha_s^v$ . As can be seen in Fig. 1, larger coupling leads to faster chemical equilibration. The fugacities for both gluons and quarks at  $\alpha_s = 0.8$  rise faster than those at  $\alpha_s = 0.5$ , which in turn, are faster than those at  $\alpha_s = 0.3$ . For gluon, the fugacities at around 4.0 fm/c at LHC and at around 6.0 fm/c at RHIC in all cases are already reasonably close to 1.0, whereas those for quarks vary widely with the value of  $\alpha_s$ . Larger  $\alpha_s$  gives much better results for quarks. The curves for  $\alpha_s^v$  tend to move in time across those with fixed  $\alpha_s$  because

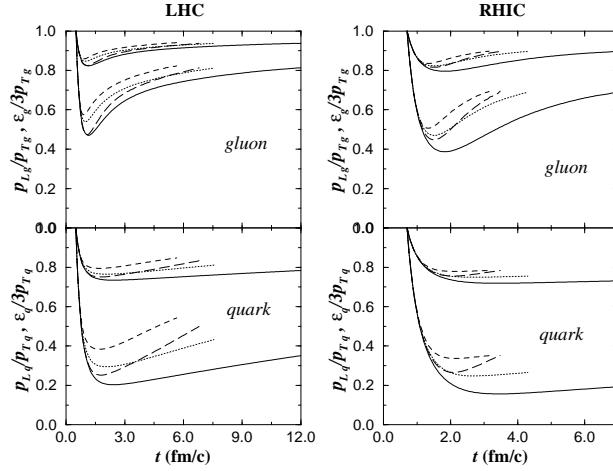


**Fig. 1.** Time evolution of parton fugacities and temperature. Solid, dotted, dashed and long dashed are for  $\alpha_s = 0.3, 0.5, 0.8$  and  $\alpha_s^v$ , respectively.

of the drop in the average parton energies due to the expansion and parton creation which lead to a decrease of the average momentum exchange and hence an increase of  $\alpha_s^v$ . The resulting curves then tend to move from curves of smaller to larger  $\alpha_s$ . Thus if we use  $\alpha_s^v$ , which seems to be a more consistent choice, parton chemical equilibration will be faster and improved significantly in the case of quarks. For gluon, it is hard to get any obvious improvement when chemical equilibration is already very good near the end of the time evolution.

In the case of kinetic equilibration, something similar happens. In Fig. 2, the ratio of longitudinal to transverse pressure as well as one third of the energy density to transverse pressure are plotted. When the momentum distribution is isotropic as in a thermalized system, these ratios are 1.0. This is the case at the start of the evolution because of our momentarily thermalized initial conditions. As the evolution starts, the expansion pushes the plasma out of equilibrium and isotropy is lost. The ratios are seen to deviate from 1.0. At some point in time, net interactions become fast enough in response to the expansion and bring the plasma back towards equilibrium so the curves make a turn and rise again towards isotropy.

In the initial stage, there is not much difference between cases with different values of  $\alpha_s$  because this is the expansion dominated phase. Larger  $\alpha_s$ , however, causes the interactions to take over sooner and achieve at the end a better degree of kinetic equilibration both for quarks and for gluons. Like chemical equilibration, only quarks but not gluons show considerable improvement in the end degree of kinetic equilibration. Again,  $\alpha_s^v$  is better equilibrated than that of the  $\alpha_s = 0.3$  case due to the increasing  $\alpha_s$ .



**Fig. 2.** Time evolution of the pressure ratios (bottom set of 4 curves in each plot) and energy to pressure ratios (upper set of 4 curves) . The assignment of the values of  $\alpha_s$  to the curves are the same as in Fig. 1.

These improvements are, however, accompanied by a reduction of the duration of the parton phase resulting from more rapid cooling (Fig. 1). This comes about because of enhanced gluon multiplication and conversion into quark-antiquark pairs while the quarks have to expand against a stronger pressure. So a consistent  $\alpha_s = \alpha_s^v$  speeds up and improves equilibration for the partons but only at the expense of the duration of the deconfined phase.

In summary, because different values of the coupling have rather large effects on equilibration, we argued that a time evolving averaged coupling, which reflects the decrease of the average parton energies of the system, should be used in studying the time evolution in high energy nuclear collisions. This more consistent approach enhances the equilibration process both in speed and in bringing the system closer to full equilibration.

## References

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